DW_dct_2d

Two Dimensional Discrete Cosine Transform

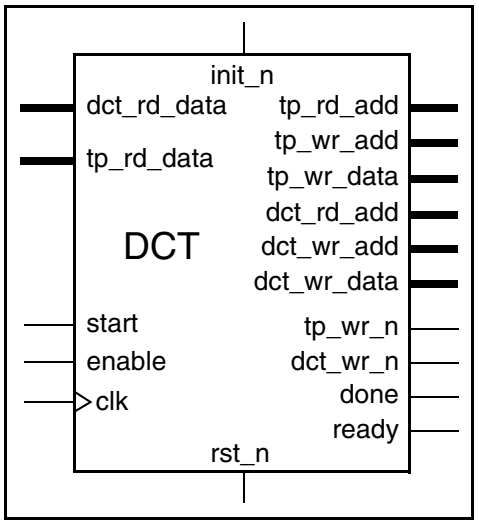
Version, STAR and Download Information: IP Directory

Features and Benefits

- Parameterized input data width and block size
- Parameterized coefficients

Applications

- Linear DCT for audio such as Dolby Digital
- NxN matrix for jpeg mjpeg/mpeg and DV video
- Dolby AC2 and AC3: 1-D DCT
- JPEG (still images): 2-D DCT spatial compression
- MPEG1 and MPEG2: 2-D DCT plus motion compensation
- H.261 and H.263: moving image compression for video conferencing and video telephony



Revision History

Description

The DW_dct_2d implements the type-II DCT (DCT-II), which can be used in signal processing and data compression. For details, see "Functional Description" on page 5.

Component pins are described in Table 1-1 and configuration parameters in Table 1-2 on page 2.

Table 1-1 Pin Description

Pin Name	Width	Direction	Function
clk	1 bit	input	Clock
rst_n	1 bit	input	Asynchronous reset; active low
init_n	1 bit	input	Synchronous reset; active low
enable	1 bit	input	Enable run
start	1 bit	input	Start transform
dct_rd_data	When `idct_mode`=0: ■ *bpp* bits When `idct_mode`=1: ■ (*n*/2+*bpp*) bits	input	Read data input port

Table 1-1 Pin Description (Continued)

Pin Name	Width	Direction	Function
tp_rd_data	When (`tc_mode`=0 and `idct_mode`=0): ■ (3*bpp*/2+5) bits When (`tc_mode`=1 or `idct_mode`=1): ■ (3*bpp*/2+4) bits	input	Read data from transpose RAM
done	1 bit	Output	Read data input done
ready	1 bit	Output	First transformed data ready
dct_rd_add	clog2(n^2) bits	Output	Read address for input data
tp_rd_add	clog2(n^2) bits	Output	Read address for transpose RAM
tp_wr_add	clog2(n^2) bits	Output	Write address for transpose RAM
tp_wr_n	1 bit	Output	Write to transpose RAM (active low)
dct_wr_n	1 bit	Output	Write output signal (active low)
tp_wr_data	When (`tc_mode`=0 and `idct_mode`=0): ■ (3*bpp*/2+5) bits When (`tc_mode`=1 or `idct_mode`=1): ■ (3*bpp*/2+4) bits	Output	Data out to transpose RAM
dct_wr_add	clog2(n^2) bits	Output	Write address for transformed data
dct_wr_data	When `idct_mode`=0: ■ (*n*/2+*bpp*) bits When `idct_mode`=1: ■ *bpp* bits	Output	Transformed data out

Configuration parameters are described in Table 1-2.

Table 1-2 Parameter Description

Parameter	Value	Description
n	4 - 16 Default: 8	Size of two dimensional matrix to be transformed It must be even and between 4 and 16, so 4, 6, 8, 10,12,14, and 16. The coefficients are generated for each size of *n*, using the formulas in "Functional Description" on page 5. The scaling factor required for each coefficient must be applied to the coefficient before inserting it in the module.
bpp	4 to 32 Default: 8	Number of bits per pixel

Table 1-2 Parameter Description (Continued)

Parameter	Value	Description
reg_out	0 or 1 Default: 0	Register outputs
tc_mode	0 or 1 Default: 0	Input data type: two's complement Determines the data type of the input data, for forward dct mode only. ■ 0 = The data is assumed to be non-negative ■ 1 = The data is considered two's complement Intermediate data and output data is always in two's complement mode.
rt_mode	0 or 1 Default: 1	Determines the output rounding or truncate ■ 0 = Round the data to the nearest up ■ 1 = Truncate the data at the output width NOTE: two's complement data is output always, and truncation causes errors or weighting to negative numbers.
idct_mode	0 or 1 Default: 0	Determines the direction of data throughput and the size of the various ports ■ 0 = The data is assumed to be pixel or sample data and the forward DCT algorithm is used; the input is bpp, and the output is *n*/2+*bpp* ■ 1 = The input is considered to be DCT data. The width of the input is *n*/2+*bpp* bits and the output is *bpp* bits.
co_a	16 bits Default: 23170	Coefficient A All DCT coefficients are calculated by the formula: $$Coef(i) = \begin{cases} C(0) = \frac{1}{\sqrt{n}} & when\ i = 0 \\ C(1)\cos\left(\frac{i\pi}{2n}\right) = \sqrt{\frac{2}{n}}\cos\left(\frac{i\pi}{2n}\right) & when\ i > 0 \end{cases}$$ Where i=0 corresponds to *co_a*, i=1 corresponds to *co_b*, and so on.
co_b	16 bits Default: 32138	Coefficient B
co_c	16 bits Default: 30274	Coefficient C
co_d	16 bits Default: 27245	Coefficient D
co_e	16 bits Default: 18205	Coefficient E
co_f	16 bits Default: 12541	Coefficient F

Table 1-2 Parameter Description (Continued)

Parameter	Value	Description
co_g	16 bits Default: 6393	Coefficient G
co_h	16 bits Default: 35355	Coefficient H
co_i	16 bits Default: 49039	Coefficient I
co_j	16 bits Default: 46194	Coefficient J
co_k	16 bits Default: 41573	Coefficient K
co_l	16 bits Default: 27779	Coefficient L
co_m	16 bits Default: 19134	Coefficient M
co_n	16 bits Default: 9755	Coefficient N
co_o	16 bits Default: 35355	Coefficient O
co_p	16 bits Default: 49039	Coefficient P

Table 1-3 Synthesis Implementations

Implementation Name	Function	License Feature Required
rtl	Synthesis model	DesignWare

Table 1-4 Simulation Models

Model	Function
DW01.DW_DCT_2D_CFG_SIM	Design unit name for VHDL simulation
dw/dw01/src/DW_dct_2d_sim.vhd	VHDL simulation model source code
dw/sim_ver/DW_dct_2d.v	Verilog simulation model source code

Functional Description

Contemporary image/audio data processing applications use transform coding as an integral part of the efficient storage and transmission of signals. Current transmission and storage systems require a reduction in data stream size. Conversely, the transmission medium attempts to add redundant information to obtain the highest possible transmission quality. In order to achieve the reduction in data stream size, we need to devise a method of compression or elimination of data.

The discrete cosine transforms forms an integral part of current digital signal processing. The basis of the utility of the transform function relies on the fact that most analog waveforms perceptible to humans contain a large amount of redundant information. This redundancy exists as correlation between neighboring data samples in the digital domain. In still image processing, the redundant information is contained in the relative similarity between neighboring pixels. In order to achieve reduction in data stream size, the transform attempts to remove as much of the redundancy as is possible. Transforms perform a perfect, or lossless transformation of the data as spatial displacements into spatial frequencies. The inverse function reverses this transform and recovers the image data perfectly. The only loss involved in this transform is due to accuracy/truncation/rounding and another step outside of the transform called quantization.

The DW_dct_2d implements the DCT-II. This is described in detail below. The device uses coefficients and data at the input port and generates the DCT data at the output. The data is read using radd, and the forward DCT data is read by rows (0,1,2 to $n*n$-1). The inverse DCT (IDCT) reads data by columns, (0,n,2n,…1,n+1,2n+1, ... to $n*(n-1)$). This device requires an intermediate RAM to hold the first pass results. This RAM is written by columns and read by rows. It is read continuously and written at `tp_wr_n`. If continuous stream data is being converted, a dual-length RAM and a toggle method is necessary. This allows the initial data to be written into the transposition memory and then toggled, and the next block is then written to the new transposition memory while the initial data is read from the first transposition block. In this way, the intermediate terms are continually written and read.

The method used for the DCT formula follows. The DCT-II is the most commonly used equation, and is the one referred to when we say DCT. The 1-D DCT formulas are:

1-D DCT (equation (1))

$$X(k) = \sum_{p=0}^{n-1} x(p)C(p)\cos\left(\frac{(2p+1)k\pi}{2n}\right)$$

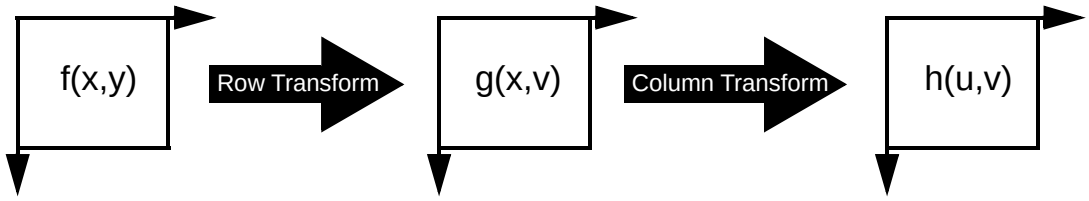
2-D DCT (equation (2))

$$X(k,j) = C(k)C(j)\sum_{p=0}^{n-1}\left(\sum_{m=0}^{n-1} x(p,m)\cos\left(\frac{(2m+1)k\pi}{2n}\right)\right)\cos\left(\frac{(2p+1)j\pi}{2n}\right)$$

where

$$C(i) = \begin{cases} \frac{1}{\sqrt{n}} & for \quad i = 0 \\ \sqrt{\frac{2}{n}} & otherwise \end{cases}$$

This property, separability, allows the transform of a 2-D image to be computed in two steps by successive 1-D operations. First, do the operation of a 1-D transform on the row data, and then the second operation on the resulting data in by column.



This device uses the intermediate memory to hold the g(x,v) results listed above.

The scaled coefficients provided as parameters are defined by the following formula:

$$Coef(i) = \begin{cases} C(0) = \frac{1}{\sqrt{n}} & when\ i = 0 \\ C(1)\cos\left(\frac{i\pi}{2n}\right) = \sqrt{\frac{2}{n}}\cos\left(\frac{i\pi}{2n}\right) & when\ i > 0 \end{cases}$$

Where i=0 corresponds to *co_a*, i=1 corresponds to *co_b*, and so on.

These scaled coefficients can be generated using the following Perl script (call it gen_coef.pl):

```
#!/usr/local/bin/perl -w
use Math::Trig;
$N  = 8;
if(defined $ARGV[0]){
  $N  = $ARGV[0];
  }
my $colcnt = 0;
my $rowcnt = 0;
  for ($rowcnt = 0; $rowcnt < $N ; $rowcnt += 1) {#col
      $Alpha = 1/sqrt($N) if $rowcnt == 0;#scaling factor
      $Alpha = sqrt(2/$N) if $rowcnt != 0;#scaling factor
      $rad = (($Alpha*(cos(((2*$colcnt +1)*$rowcnt*pi)/(2*$N)) )));
      $rad /= 1.52590;# convert to decimal fraction
      $rad *= 1000000;#scale up
      $rad += 0.5;#round up
      $rad /= 10;#round up
      #$rad = int($rad);
      $rad = sprintf("%04d",$rad ) ;#set decimal places
      print "$rad\n";
  }
```

This script will print a series of coefficients based on the 'n' number provided. For example, '`gen_coef.pl` 8' will generate coefficients for an 8x8 DCT matrix.

Timing Diagrams

Figure 1-1 displays timing from `start` to the first `tp_wr_n` write to transpose memory, for forward DCT.

Figure 1-1 'start' to the First 'tp_wr_n' Write to Transpose Memory

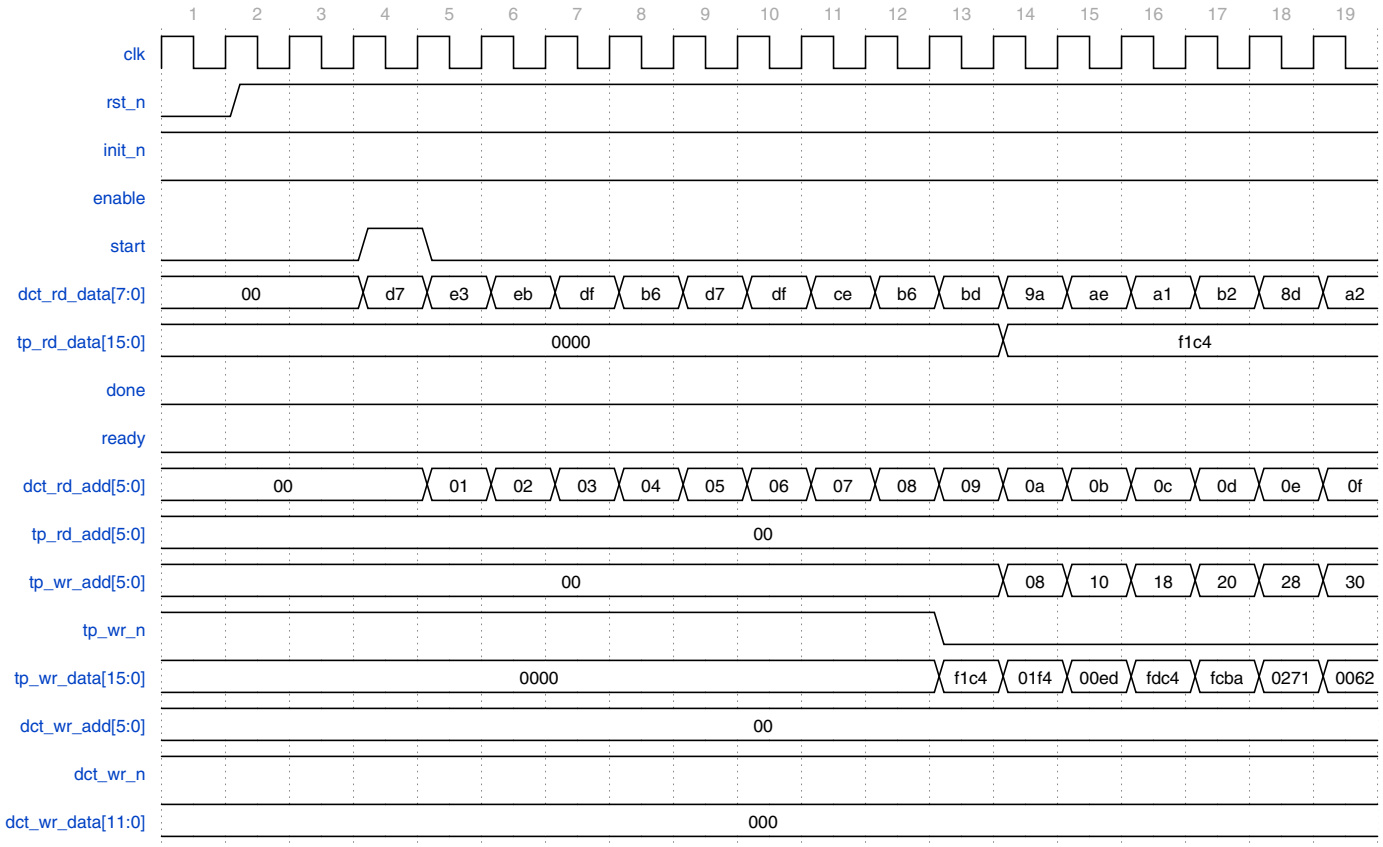
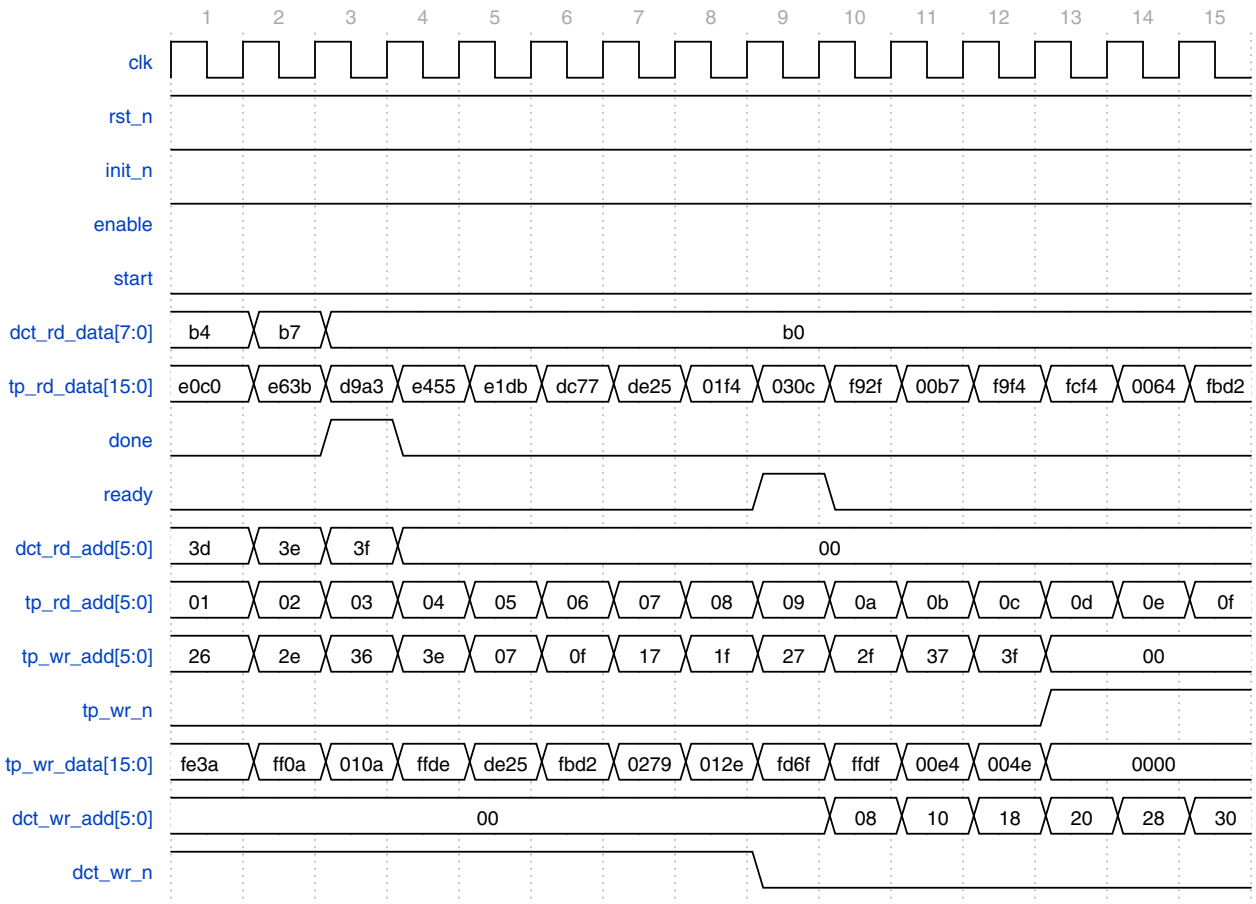


Figure 1-2 on page 9 presents the Done/Ready timing diagram that shows, for $n = 8$, the timing of the signal `done` output to the `ready` output. The `done` signal signifies the last input data has been read, while `ready` signifies the last transform data is ready.

Figure 1-2 Done / Ready Timing



Related Topics

- Math – Arithmetic Overview
- DesignWare Building Block IP User Guide

HDL Usage Through Component Instantiation - VHDL

```
library IEEE,DWARE,WORK;
use IEEE.std_logic_1164.all;
use DWARE.DWpackages.all;

entity DW_dct_2d_inst is
  generic (
    inst_bpp : NATURAL := 8;
    inst_n : NATURAL := 8;
    inst_reg_out : NATURAL := 0;
    inst_tc_mode : NATURAL := 0;
    inst_rt_mode : NATURAL := 1;
    inst_idct_mode : NATURAL := 0;
    inst_co_a : NATURAL := 23170;
    inst_co_b : NATURAL := 32138;
    inst_co_c : NATURAL := 30274;
    inst_co_d : NATURAL := 27245;
    inst_co_e : NATURAL := 23170;
    inst_co_f : NATURAL := 18205;
    inst_co_g : NATURAL := 12541;
    inst_co_h : NATURAL := 6393;
    inst_co_i : NATURAL := 00000;
    inst_co_j : NATURAL := 00000;
    inst_co_k : NATURAL := 00000;
    inst_co_l : NATURAL := 00000;
    inst_co_m : NATURAL := 00000;
    inst_co_n : NATURAL := 00000;
    inst_co_o : NATURAL := 00000;
    inst_co_p : NATURAL := 00000
    );
  port (
    inst_clk : in std_logic;
    inst_rst_n : in std_logic;
    inst_init_n : in std_logic;
    inst_enable : in std_logic;
    inst_start : in std_logic;
    inst_dct_rd_data : in std_logic_vector(inst_bpp+(inst_n/2*inst_idct_mode)-1 downto
0);
    inst_tp_rd_data : in std_logic_vector(inst_bpp/2+inst_bpp+3+((1-inst_tc_mode)*(1-
inst_idct_mode)) downto 0);
    tp_rd_add_inst : out std_logic_vector(bit_width(inst_n*inst_n)-1 downto 0);
    tp_wr_add_inst : out std_logic_vector(bit_width(inst_n*inst_n)-1 downto 0);
    tp_wr_data_inst : out std_logic_vector(inst_bpp/2+inst_bpp+3+((1-inst_tc_mode)*(1-
inst_idct_mode)) downto 0);
    tp_wr_n_inst : out std_logic;
    dct_rd_add_inst : out std_logic_vector(bit_width(inst_n*inst_n)-1 downto 0);
    dct_wr_add_inst : out std_logic_vector(bit_width(inst_n*inst_n)-1 downto 0);
    dct_wr_n_inst : out std_logic;
```

```
    done_inst : out std_logic;
    ready_inst : out std_logic;
    dct_wr_data_inst : out std_logic_vector(inst_bpp-1+(inst_n/2*(1-inst_idct_mode))
downto 0)
    );
    end DW_dct_2d_inst;


architecture inst of DW_dct_2d_inst is

    component DW_dct_2d
      generic (
        bpp : NATURAL := 8;
        n   : NATURAL := 8;
        reg_out : NATURAL := 0;
        tc_mode : NATURAL := 0;
        rt_mode : NATURAL := 1;
        idct_mode : NATURAL := 0;
        co_a : NATURAL := 23170;
        co_b : NATURAL := 32138;
        co_c : NATURAL := 30274;
        co_d : NATURAL := 27245;
        co_e : NATURAL := 23170;
        co_f : NATURAL := 18205;
        co_g : NATURAL := 12541;
        co_h : NATURAL := 6393;
        co_i : NATURAL := 00000;
        co_j : NATURAL := 00000;
        co_k : NATURAL := 00000;
        co_l : NATURAL := 00000;
        co_m : NATURAL := 00000;
        co_n : NATURAL := 00000;
        co_o : NATURAL := 00000;
        co_p : NATURAL := 00000 );
      port (clk    : in std_logic;
        rst_n  : in std_logic;
        init_n : in std_logic;
        enable : in std_logic;
        start  : in std_logic;
        dct_rd_data : in std_logic_vector(bpp+(n/2*idct_mode)-1 downto 0);
        tp_rd_data  : in std_logic_vector(bpp/2+bpp+3+((1-tc_mode)*(1-idct_mode))
downto 0);
        tp_rd_add : out std_logic_vector(bit_width(n*n)-1 downto 0);
        tp_wr_add : out std_logic_vector(bit_width(n*n)-1 downto 0);
        tp_wr_data : out std_logic_vector(bpp/2+bpp+3+((1-tc_mode)*(1-idct_mode))
downto 0);
        tp_wr_n : out std_logic;
        dct_rd_add : out std_logic_vector(bit_width(n*n)-1 downto 0);
        dct_wr_add : out std_logic_vector(bit_width(n*n)-1 downto 0);
```

```
        dct_wr_n : out std_logic;
        done : out std_logic;
        ready : out std_logic;
        dct_wr_data : out std_logic_vector(bpp-1+(n/2*(1-idct_mode)) downto 0)
        );
    end component;

begin

    -- Instance of DW_dct_2d
    U1 : DW_dct_2d
    generic map ( bpp => inst_bpp,
                  n => inst_n,
                  reg_out => inst_reg_out,
                  tc_mode => inst_tc_mode,
                  rt_mode => inst_rt_mode,
                  idct_mode => inst_idct_mode,
                  co_a => inst_co_a,
                  co_b => inst_co_b,
                  co_c => inst_co_c,
                  co_d => inst_co_d,
                  co_e => inst_co_e,
                  co_f => inst_co_f,
                  co_g => inst_co_g,
                  co_h => inst_co_h,
                  co_i => inst_co_i,
                  co_j => inst_co_j,
                  co_k => inst_co_k,
                  co_l => inst_co_l,
                  co_m => inst_co_m,
                  co_n => inst_co_n,
                  co_o => inst_co_o,
                  co_p => inst_co_p )
    port map ( clk => inst_clk,
                  rst_n => inst_rst_n,
                  init_n => inst_init_n,
                  enable => inst_enable,
                  start => inst_start,
                  dct_rd_data => inst_dct_rd_data,
                  tp_rd_data => inst_tp_rd_data,
                  tp_rd_add => tp_rd_add_inst,
                  tp_wr_add => tp_wr_add_inst,
                  tp_wr_data => tp_wr_data_inst,
                  tp_wr_n => tp_wr_n_inst,
                  dct_rd_add => dct_rd_add_inst,
                  dct_wr_add => dct_wr_add_inst,
                  dct_wr_n => dct_wr_n_inst,
                  done => done_inst,
                  ready => ready_inst,
```

```
                    dct_wr_data => dct_wr_data_inst );

end inst;
```

HDL Usage Through Component Instantiation - Verilog

```
module DW_dct_2d_inst( inst_clk,
                    inst_rst_n,
                    inst_init_n,
                    inst_enable,
                    inst_start,

                    inst_dct_rd_data,
                    inst_tp_rd_data,

                    tp_rd_add_inst,
                    tp_wr_add_inst,
                    tp_wr_data_inst,
                    tp_wr_n_inst,

                    dct_rd_add_inst,
                    dct_wr_add_inst,
                    dct_wr_n_inst,

                    done_inst,
                    ready_inst,
                    dct_wr_data_inst );

parameter bpp = 8;
parameter n = 8;
parameter reg_out = 1;
parameter tc_mode = 0;
parameter rt_mode = 1;
parameter idct_mode = 1;
parameter co_a = 23170;
parameter co_b = 32138;
parameter co_c = 30274;
parameter co_d = 27245;
parameter co_e = 23170;
parameter co_f = 18205;
parameter co_g = 12541;
parameter co_h = 6393;
parameter co_i = 00000;
parameter co_j = 00000;
parameter co_k = 00000;
parameter co_l = 00000;
parameter co_m = 00000;
parameter co_n = 00000;
```

```
parameter co_o = 00000;
parameter co_p = 00000;



`define addr_width 6  // addr_width is ceil(log2(n * n))

input inst_clk;
input inst_rst_n;
input inst_init_n;
input inst_enable;
input inst_start;
input [bpp+(n/2*idct_mode)-1 : 0] inst_dct_rd_data;
input [bpp/2+bpp+3+((1-tc_mode)*(1-idct_mode)) : 0] inst_tp_rd_data;
output [`addr_width-1 : 0] tp_rd_add_inst;
output [`addr_width-1 : 0] tp_wr_add_inst;
output [bpp/2+bpp+3+((1-tc_mode)*(1-idct_mode)) : 0] tp_wr_data_inst;
output tp_wr_n_inst;
output [`addr_width-1 : 0] dct_rd_add_inst;
output [`addr_width-1 : 0] dct_wr_add_inst;
output dct_wr_n_inst;
output done_inst;
output ready_inst;
output [bpp-1+(n/2*(1-idct_mode)) : 0] dct_wr_data_inst;

    // Instance of DW_dct_2d
DW_dct_2d #(bpp, n, reg_out, tc_mode, rt_mode, idct_mode,
            co_a, co_b, co_c, co_d, co_e, co_f, co_g, co_h, co_i, co_j,
            co_k, co_l, co_m, co_n, co_o, co_p)
      U1 ( .clk(inst_clk),
               .rst_n(inst_rst_n),
               .init_n(inst_init_n),
               .enable(inst_enable),
               .start(inst_start),
               .dct_rd_data(inst_dct_rd_data),
               .tp_rd_data(inst_tp_rd_data),
               .tp_rd_add(tp_rd_add_inst),
               .tp_wr_add(tp_wr_add_inst),
               .tp_wr_data(tp_wr_data_inst),
               .tp_wr_n(tp_wr_n_inst),
               .dct_rd_add(dct_rd_add_inst),
               .dct_wr_add(dct_wr_add_inst),
               .dct_wr_n(dct_wr_n_inst),
               .done(done_inst),
               .ready(ready_inst),
               .dct_wr_data(dct_wr_data_inst) );

endmodule
```

Revision History

For notes about this release, see the *DesignWare Building Block IP Release Notes*.

For lists of both known and fixed issues for this component, refer to the STAR report.

For a version of this datasheet with visible change bars, click here.

Date	Release	Updates
July 2021	DWBB_202106.1	■ Removed redundant text on page 1 ■ Added the Width column and two missing pins to Table 1-1 on page 1 ■ Added coefficient formula for coefficient parameters in Table 1-2 on page 2 and on page 7 ■ Updated the 1-D DCT formula on page 6 and the coefficient formula on page 6 ■ Updated the flow diagram on page 6 ■ Updated the waveform diagrams on page 8 and page 9 ■ Updated the instantiation examples on page 10 and page 13 ■ Added this Revision History table and the document links on this page

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